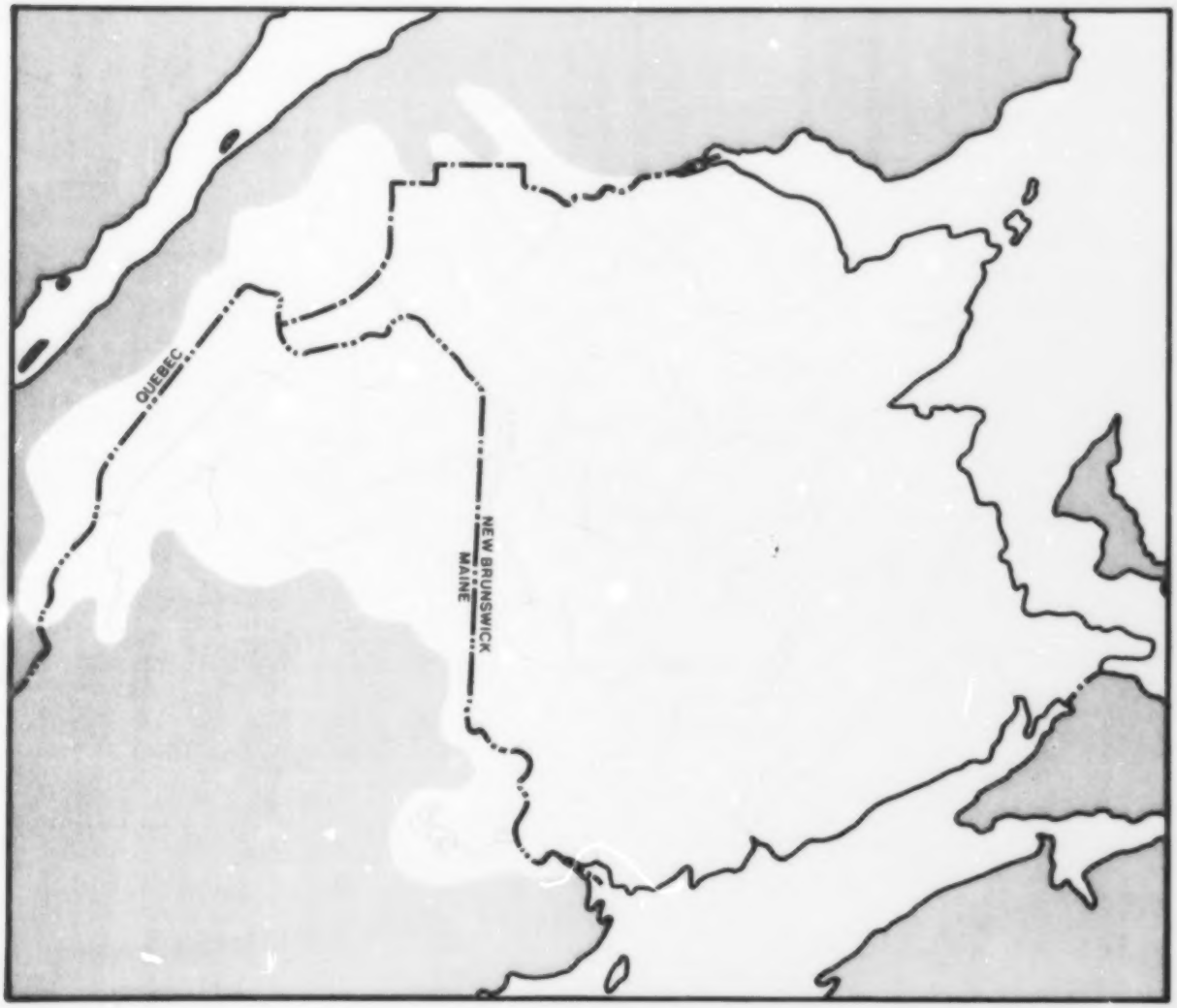
Low Flow Estimation Guidelines For New Brunswick



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Water Resource Planning Branch
Direction de la planification des ressources en eau

LOW FLOW ESTIMATION GUIDELINES

FOR NEW BRUNSWICK

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TABLE OF CONTENTS

Page No.

Title Page
Table of Contents i
List of Figures ii
List of Tables iii
List of Symbols and Abbreviations iv
Acknowledgements v
Disclaimer vi

1. INTRODUCTION 1

2. SINGLE STATION LOW FLOW FREQUENCY ANALYSES 2

   2.1 Streamflow data 2
   2.2 Low Flow Frequency Analyses 6

3. REGIONAL LOW FLOW FREQUENCY ANALYSES 10

   3.1 Analysis Methodology 10
   3.2 Regression Analysis Results 12
   3.3 Envelope Curves 19

4. APPLICATIONS PROGRAM 23

5. LOW FLOW ESTIMATION PROCEDURE DESCRIPTION 25

   5.1 General 25
   5.2 Low Flow Estimation at Gauged Sites 26
   5.3 Low Flow Estimation at Ungauged Sites 27

6. ILLUSTRATIVE EXAMPLES 33

7. REFERENCES 43

LIST OF FIGURES

Figure	Title	Page
1	Homogeneous Low Flow Regions and Hydrometric Stations Used in the Analysis	5
2	Mean Annual Precipitation (1951-1980)	14
3	Low Flow Envelope Curves	21

LIST OF TABLES

Table	Title	Page
1	Selected Hydrometric Stations	3
2	One-Day Low Flows	7
3	Seven-Day Low Flows	8
4	Fourteen-Day Low Flows	9
5	Physiographic and Climatic Variables for Selected Gauged Watersheds	13
6	Regional Regression Equations for the Northern Region	15
7	Regional Regression Equation for the Southern Region Basins with Drainage Basin Areas $\geq$ 400 km^2	17
8	Regional Regression Equations for the Southern Region Basins with Drainage Basin Areas < 400 km^2	18

LIST OF SYMBOLS AND ABBREVIATIONS

km^2	- square kilometres
mm	- millimetres
m^3/s	- cubic metres per second
r	- multiple regression coefficient
yr	- year
AL&S	- area occupied by lakes and swamps (km^2)
D	- duration in days
DA	- drainage area in km^2
%L&S	- percentage of area occupied by lakes and swamps
LAT	- latitude in degrees ($^\circ$), decimal form
LF	- low flow estimate in cubic metres per second
LONG	- longitude in degrees ($^\circ$), decimal form
MAR	- mean annual runoff estimates from hydrometric station flow data (mm)
MAP	- mean annual precipitation in mm
P	- basin perimeter in km
Q_T	- one day duration low flow of T years return period from envelope curves
S.E.	- standard error (m^3/s) of the estimate
SNOW	- average water equivalent (in mm) of the snowpack on March 31
T_2	- return period in years
r^2	- coefficients of determination
<	- less than
≥	- greater than or equal to
°	- degrees

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DISCLAIMER

Even though the techniques outlined in this report represent the current state of knowledge about low flow estimation, a certain amount of uncertainty is associated with their application. Neither Environment Canada nor the New Brunswick Department of the Environment assume any liability for the misuse or misunderstanding of the information presented in this report. The user is expected to make the final evaluation of the appropriateness of the techniques and the accuracy of the data in his or her own set of circumstances.

1.0 INTRODUCTION

Naturally occuring low streamflow information has many uses. Engineers need to consider low flows during the design of water supplies, water treatment plants, sewage treatment plants, hydraulic structures and navigation works. Biologists need low flow information when considering the effects of streamflow on aquatic flora and fauna. Still other uses for low flow information may be found in the areas of river navigation, reservoir operation and aquatic-based recreation.

This report presents guidelines for the estimation of low streamflows in New Brunswick. However, it does not replace the need for sound engineering judgement in estimating low flows or in applying the estimates to a particular problem situation.

The following section deals with the results of single station frequency analyses for the 38 streamflow sites used in this study. Section 3 describes the regional frequency analysis and the development of envelope curves. Section 4 describes the "HIGHLOW" computer program to estimate both flood and low flows. Section 5 summarizes procedures for estimating low flows in gauged and ungauged basins. Finally, illustrative examples are provided in Section 6.

2.0 SINGLE STATION LOW FLOW FREQUENCY ANALYSIS

2.1 Streamflow Data

Not all hydrometric station data in New Brunswick can contribute sufficient information to estimate low flows of a given duration and for a given return period. The quality of some hydrometric station data is known to be poor when the flows are low. Furthermore, any regulation in a basin will alter the natural sequence of flows and not allow a definition of the true low flow regime. Low flows are particularly susceptible to any form of regulation. This is in contrast to the effects of regulation on flood flows. Regulation which has little or no effect on flood discharges may still significantly affect low flows.

Obviously, the longer the period of record, the better a low flow estimate will be at that site providing the data are hydraulically accurate. As a consequence, only natural flow hydrometric stations with at least 10 years of record and with sufficiently accurate data at low flows were selected for analysis. In addition to the hydrometric stations in New Brunswick, station 01DL001 (Kelly River at Eight Mile Ford), located in Nova Scotia near the New Brunswick border, was employed. The 38 stations selected are listed in Table 1 with their period of record, minimum recorded discharge and drainage area. Their locations are shown on Figure 1.

TABLE 1

SELECTED HYDROMETRIC STATIONS

Station Description	Drainage Area (km^2)	Period of Record	Minimum Recorded Daily Flow (m^3/s)
01AD002 Saint John River at Fort Kent	14700	1927-88	14.4
01AD003 St. Francis River at Outlet of Glasier Lake	1350	1952-88	1.69
01AG002 Limestone Stream at Four Falls	199	1968-88	0.142
01AJ003 Meduxnekeag River near Belleville	1210	1968-88	0.459
01AJ004 Big Presque Isle Stream at Tracey Mills	484	1968-88	0.178
01AJ010 Becaguimec Stream at Coldstream	350	1974-88	0.270
01AJ011 Cold Stream at Coldstream	156	1974-88	0.057
01AK001 Shogomoc Stream near Trans Canada Hwy	234	1919-41,44-88	0.048
01AK007 Nackawic Stream near Temperance Vale	240	1968-88	0.016
01AK008 Eel River near Scott Siding	531	1974-88	0.116
01AL002 Nashwaak River at Durham Bridge	1450	1962-88	2.58
01AL003 Hayden Brook near Narrows Mountain	6.48	1971-88	0.012
01AM001 North Branch Oromocto River at Tracy	557	1963-88	0.013
01AN001 Castaway Stream near Castaway	34.4	1972-88	0.033
01AN002 Salmon River at Castaway	1050	1974-88	1.19
01AP002 Canaan River at East Canaan	668	1926-41,63-88	0.057
01AP004 Kennebecasis River at Apohaqui	1100	1961-88	1.01
01AP006 Nerepis River near Fowlers Corner	293	1976-88	0.020
01AQ001 Lepreau River at Lepreau	239	1917-88	0.028
01BC001 Restigouche River below Kedgwick River	3160	1963-88	5.41
01BE001 Upsalquitch River at Upsalquitch	2270	1919-33,44-88	2.24
01BJ001 Tetagouche River near West Bathurst	363	1923-33,52-88	0.322

TABLE 1 (continued)

SELECTED HYDROMETRIC STATIONS

Station Description	Drainage Area (km^2)	Period of Record	Minimum Recorded Daily Flow (m^3/s)
01BJ003 Jacquet River near Durham Centre	510	1965-88	0.500
01BL001 Bass River at Bass River	175	1966-88	0.012
01BL002 Riviere Caraquet at Burnsville	173	1970-88	0.345
01BL003 Big Tracadie River at Murchy Bridge Crossing	383	1971-88	0.793
01BO001 Southwest Miramichi River at Blackville	5050	1919-33,62-88	9.34
01BO002 Renous River at McGraw Brook	611	1966-88	0.677
01BO003 Barnaby River below Semiwagan River	484	1973-88	0.272
01BP001 Little Southwest Miramichi R. at Lyttleton	1340	1952-88	1.70
01BQ001 Northwest Miramichi River at Trout Brook	948	1962-88	1.42
01BR001 Kouchibouguac River near Vautour	177	1971-88	0.184
01BS001 Coal Branch River at Beersville	166	1965-88	0.065
01BU002 Petitcodiac River near Petitcodiac	391	1962-88	0.102
01BU003 Turtle Creek at Turtle Creek	129	1963-88	0.203
01BU004 Palmers Creek near Dorchester	34.2	1967-84	0.014
01BV006 Point Wolfe River at Fundy National Park	130	1964-88	0.108
01DL001 Kelley River at Eight Mile Ford	63.2	1970-88	0.020

Fig. 1 Homogeneous Low Flow Regions and Hydrometric Stations used in the analysis.

The daily discharges at these stations were used to estimate on an annual basis, the minimum 1-day, 7-day and 14-day duration mean flows with the MEANS computer program developed by Environment Canada. A water year from May 1 to April 30 was selected for the analysis. The series of annual minimums of each duration were fitted to the Gumbel III frequency distribution in order to assess low flows of that duration for a given return period, as detailed in the next section.

2.2 Low Flow Frequency Analyses

A single station low flow frequency analysis was performed using the LOFLOW program (Condie and Cheng, 1982) for each of the 38 stations listed in Table 1 using their 1-day, 7-day and 14-day low flows. The calculated 2 year, 10 year, 20 year and 50 year low flows of 1-day, 7-day and 14-day durations are given in Tables 2, 3 and 4 respectively. Return periods of 50 years and greater were not included in this regional study because of the large uncertainty associated with their estimates. Durations of 1, 7 and 14 days for 2, 10 and 20 year return periods were employed in deriving the regional equations as detailed in the next section.

Generally, low flow estimates are less reliable than estimates for high flows due to the considerable variability of geology which affects groundwater inflow to the stream. Also, the effect of regulation on low flows is significant and this limits the availability of useful hydrometric data for low flow analyses.

TABLE 2

ONE-DAY LOW FLOWS

Station	Low Flow (m^3/s) 2 year	10 year	20 year	50 year
01AD002	32.5	19.7	17.6	15.9
01AD003	3.82	2.41	2.11	1.86
01AG002	0.464	0.268	0.214	0.156
01AJ003	1.19	0.521	0.460	0.426
01AJ004	0.718	0.285	0.231	0.195
01AJ010	0.499	0.325	0.294	0.270
01AJ011	0.213	0.096	0.077	0.062
01AK001	0.289	0.101	0.077	0.060
01AK007	0.079	0.023	0.016	0.013
01AK008	0.589	0.159	0.102	0.061
01AL002	3.87	2.79	2.64	2.53
01AL003	0.022	0.015	0.014	0.013
01AM001	0.439	0.061	0.022	0.0
01AN001	0.086	0.046	0.039	0.034
01AN002	2.11	1.27	1.16	1.09
01AP002	0.476	0.160	0.115	0.083
01AP004	2.82	1.60	1.32	1.07
01AP006	0.249	0.071	0.028	0.0
01AQ001	0.410	0.109	0.072	0.047
01BC001	9.96	7.00	6.34	5.73
01BE001	5.80	3.59	3.12	2.70
01BJ001	0.681	0.401	0.365	0.341
01BJ003	0.999	0.628	0.565	0.515
01BL001	0.090	0.031	0.022	0.015
01BL002	0.675	0.430	0.389	0.356
01BL003	1.57	0.985	0.891	0.819
01BO001	19.4	12.7	11.3	10.1
01BO002	1.30	0.754	0.689	0.646
01BO003	0.596	0.316	0.268	0.230
01BP001	5.18	3.07	2.58	2.12
01BQ001	2.83	1.82	1.64	1.48
01BR001	0.426	0.251	0.216	0.186
01BS001	0.199	0.096	0.081	0.070
01BU002	0.442	0.183	0.146	0.119
01BU003	0.332	0.238	0.222	0.209
01BU004	0.041	0.018	0.015	0.011
01BV006	0.381	0.168	0.139	0.118
01DL001	0.087	0.038	0.026	0.014

TABLE 3

SEVEN-DAY LOW FLOWS

Station	Low Flow (m^3/s) 2 year	10 year	20 year	50 year
01AD002	34.4	20.5	18.2	16.3
01AD003	4.00	2.53	2.23	1.96
01AG002	0.517	0.311	0.251	0.185
01AJ003	1.50	0.655	0.565	0.509
01AJ004	0.997	0.405	0.296	0.206
01AJ010	0.599	0.384	0.342	0.306
01AJ011	0.258	0.117	0.093	0.073
01AK001	0.321	0.117	0.091	0.074
01AK007	0.116	0.032	0.021	0.014
01AK008	0.719	0.213	0.135	0.076
01AL002	4.38	2.98	2.77	2.62
01AL003	0.025	0.017	0.015	0.014
01AM001	0.512	0.084	0.039	0.012
01AN001	0.092	0.050	0.043	0.038
01AN002	2.24	1.32	1.21	1.13
01AP002	0.568	0.172	0.120	0.084
01AP004	3.06	1.77	1.52	1.31
01AP006	0.317	0.072	0.017	0.0
01AQ001	0.498	0.143	0.097	0.066
01BC001	10.0	7.56	7.17	6.87
01BE001	6.21	3.89	3.38	2.91
01BJ001	0.693	0.447	0.426	0.413
01BJ003	1.05	0.665	0.600	0.549
01BL001	0.109	0.039	0.028	0.019
01BL002	0.718	0.467	0.426	0.394
01BL003	1.63	1.00	0.907	0.834
01BO001	20.3	13.7	12.5	11.5
01BO002	1.53	0.892	0.807	0.748
01BO003	0.668	0.377	0.333	0.301
01BP001	5.62	3.43	2.94	2.48
01BQ001	3.05	1.97	1.77	1.61
01BR001	0.458	0.282	0.251	0.226
01BS001	0.228	0.113	0.098	0.088
01BU002	0.487	0.229	0.198	0.178
01BU003	0.365	0.263	0.249	0.239
01BU004	0.057	0.029	0.023	0.018
01BV006	0.465	0.205	0.167	0.139
01DL001	0.100	0.041	0.031	0.022

TABLE 4

FOURTEEN-DAY LOW FLOWS

Station	Low Flow (m^3/s) 2 year	10 year	20 year	50 year
01AD002	36.9	21.6	19.0	16.8
01AD003	4.20	2.65	2.33	2.03
01AG002	0.562	0.348	0.287	0.222
01AJ003	1.79	0.756	0.629	0.544
01AJ004	1.15	0.478	0.343	0.224
01AJ010	0.715	0.437	0.368	0.300
01AJ011	0.303	0.142	0.116	0.095
01AK001	0.342	0.133	0.110	0.096
01AK007	0.140	0.032	0.021	0.015
01AK008	0.813	0.255	0.169	0.104
01AL002	4.65	3.22	3.04	2.92
01AL003	0.027	0.018	0.017	0.015
01AM001	0.587	0.086	0.040	0.013
01AN001	0.101	0.055	0.048	0.042
01AN002	2.3[illegible]	1.40	1.27	1.19
01AP002	0.6[illegible]	0.177	0.124	0.090
01AP004	3.26	1.93	1.74	1.60
01AP006	0.39[illegible]	0.096	0.031	0.0
01AQ001	0.578	0.168	0.118	0.084
01BC001	10.3	7.83	7.47	7.22
01BE001	6.56	4.11	3.56	3.05
01BJ001	0.737	0.463	0.438	0.424
01BJ003	1.09	0.688	0.620	0.567
01BL001	0.129	0.046	0.032	0.021
01BL002	0.732	0.502	0.475	0.458
01BL003	1.70	1.03	0.932	0.855
01BO001	21.7	14.6	13.3	12.2
01BO002	1.73	0.978	0.887	0.827
01BO003	0.726	0.415	0.372	0.341
01BP001	6.01	3.76	3.26	2.80
01BQ001	3.26	2.11	1.90	1.74
01BR001	0.487	0.305	0.277	0.256
01BS001	0.256	0.127	0.112	0.102
01BU002	0.567	0.264	0.223	0.194
01BU003	0.386	0.276	0.262	0.253
01BU004	0.074	0.034	0.027	0.021
01BV006	0.505	0.241	0.208	0.185
01DL001	0.117	0.046	0.037	0.031

3.0 REGIONAL LOW FLOW FREQUENCY ANALYSIS

3.1 Analysis Methodology

Because hydrologic characteristics differ from one drainage basin to another, the results of a single station low flow frequency analysis are best applied to locations on the same stream at or near the hydrometric station. The results may also be useful for similar nearby basins. However, the majority of water resource projects are usually undertaken where proration is not applicable. Therefore, regional relationships were developed in order to obtain low flow estimates at ungauged sites within homogeneous low flow zones having similar physiographic and climatic characteristics.

These homogeneous regions were defined by examining the single station low flow frequency analysis, as well as physiographic and climatic characteristics. Regional regression equations for the ten year return period, 7 day duration low flow were then determined and the regional and single station low flow estimates for stations near regional boundaries were compared. This led to further refinements of the homogeneous regions and thus the boundary between the Northern and Southern Regions was finalized as shown in Figure 1.

The boundary bisects the Miramichi River watershed. The Northwest Miramichi River and its tributaries are considered to be within the Northern Region. The Southwest Miramichi River and its tributaries are considered to be within the Southern Region.

However, if a drainage basin under consideration is near or borders the boundary between the regions, it may be worthwhile to compare the results obtained using the appropriate relationships for both the Northern Region and Southern Region.

The drainage area, basin perimeter, mean annual precipitation, and latitude were variables found useful in low flow estimation. Other physiographic and climatic variables such as area of lakes and swamps, mean annual runoff, longitude, and average water content of the snow cover were examined, but they did not further improve low flow estimates using the regional equations.

Geology has a significant influence on low flows as it affects groundwater flow into a stream. Springs may be a major source of streamflow during a low flow period. Evaluating the effect of geology on low flows, however, is difficult. An attempt was made to relate indices of groundwater availability in the regression analysis. Although this particular groundwater indicae did not further improve the regional regression estimates, this area of investigation has considerable potential and should be considered in subsequent studies.

Regional regression analyses consist of determining relationships between the low flows (the independent variable) of given return period and durations at locations with streamflow

records and physiographic and/or climatic dependent variables (shown in Table 5) describing the watersheds draining to those locations.

The regression analyses were performed on various subsets of the complete data set, namely for Province-wide, northern and southern homogeneous low flow regions, and for various basin sizes.

3.2 Regression Analysis Results

Regression equations were derived for the Northern Region (all basin sizes); as well as for the Southern Region with one equation for basin drainage areas greater than or equal to 400 km^2 and another equation for drainage basin areas less than 400 km^2.

The Northern Region equation is in the general form:

$$LF_{T,D} = (c\sqrt{DA} + d\sqrt{MAP} + k)^2$$

where LF = the low flow (m^3/s); for return period T and duration D;

DA = drainage area (km^2) upstream of the site;

MAP = the mean annual precipitation (mm) of the basin (refer to Figure 2);

c,d = regression coefficients from Table 6; and

k = regression constant from Table 6.

TABLE 5
PHYSIOGRAPHIC AND CLIMATIC VARIABLES
FOR SELECTED GAUGED WATERSHEDS

		DA (km^2)	AL&S (km^2)	%L&S	MAP (mm)	SNOW (water in mm)	PERIMETER (km)	MAR (mm)	LAT (°)	LONG (°)
01AD002	ST JOHN	14700	839.22	5.709	996.9	230.94	1183	592.10	47.2569	68.5931
01AD003	ST FRANCIS	1350	37.94	2.81	1057.9	224.17	258.95	593.34	47.2069	68.9569
01AG002	LIMESTONE	199	19.45	9.78	975	158.76	77.25	592.69	46.8283	67.7431
01AJ003	MEDUXNEKEAG	1210	67.8	5.61	957.9	156.96	233.5	669.81	46.2161	67.7283
01AJ004	BIG PRESQUE ISLE	484	17.63	3.7	925	140.17	137.55	643.10	46.4378	67.7447
01AJ010	BECAGUIMEC	350	2.68	0.77	1131.3	125.75	106.2	684.78	46.3408	67.4661
01AJ011	COLD STREAM	156	0.12	0.077	1098.1	128.76	72	652.96	46.3422	67.4692
01AK001	SHOGOMOC	234	27.95	11.94	1115	147	100.4	675.19	45.9450	67.3222
01AK007	NACKAWIC	240	12.26	5.11	1057.4	128.66	83.8	672.77	46.0492	67.2403
01AK008	EEL	531	70.4	13.26	1068.6	142.05	168.25	635.47	45.9367	67.5469
01AL002	NASHWAAK	1450	20.14	1.39	1213.4	166.56	237.25	772.09	46.1258	66.6122
01AL003	HAYDEN	6.48	0.036	0.56	1225	190	11.05	910.07	46.2989	67.0369
01AM001	N.W. OROMOCTO	557	84.31	15.13	1153.1	116.56	135.2	685.07	45.6736	66.6828
01AN001	CASTAWAY	34.4	2.27	6.6	1175	130	27	839.74	46.2983	65.7119
01AN002	SALMON	1050	67.3	6.41	1132.8	145.93	165.05	708.81	46.2911	65.7233
01AP002	CANAAN	668	23.84	3.57	1040.3	137.19	152.85	627.89	46.0719	65.3667
01AP004	KENNEBECASIS	1100	7.93	0.72	1189.1	107.55	199	728.19	45.7019	65.6013
01AP006	NEREPIS	293	3.74	1.28	1141.7	110	82.1	725.44	45.5022	66.3206
01AQ001	LEPREAU	239	24.21	10.2	1236.4	100.9	113.85	976.43	45.2033	66.4667
01BC001	RESTIGOUCHE	3160	23.03	0.73	1142.4	240.28	431.2	667.65	47.6667	67.4842
01BE001	UPSALQUITCH	2270	14.12	0.63	1084.9	231.62	305.65	573.76	47.8317	66.8817
01BJ001	TETAGOUCHE	363	8.16	2.24	988.4	234.6	148	674.16	47.6558	65.6936
01BJ003	JACQUET	510	10.24	2	1053.3	234.77	152	655.45	47.8978	66.0297
01BL001	BASS	175	14.2	8.11	1012.6	208.58	78.8	574.86	47.6500	65.5778
01BL002	CARAQUET	173	18	10.41	1125	194.36	55.96	685.41	47.7056	65.1550
01BL003	TRACADIE	383	8.96	2.34	1094	204.23	92.19	699.06	47.4350	65.1069
01BO001	S. W. MIRAMICHI	5050	177.76	3.52	1094.9	176.51	611.45	730.64	46.7361	65.8267
01BO002	RENOUS	611	38	6.22	1181.6	198.74	142.81	763.88	46.8214	66.1147
01BO003	BARNABY	484	51.64	10.67	1075	170	103.62	650.27	46.8886	65.5956
01BP001	LITTLE S.W. MIRAMICHI	1340	67.76	5.06	1183.9	222.16	259	771.93	46.9358	65.9072
01BQ001	N.W. MIRAMICHI	948	37.56	3.96	1129.9	213.2	201.07	711.89	47.0947	65.8372
01BR001	[illegible]OUCHIBOUGUAC	177	20.76	11.73	1050	160.82	66.4	682.39	46.7433	65.2047
01BS001	COAL BRANCH	166	8.67	5.23	1071.7	150	73.5	712.41	46.4436	65.0653
01BU002	PETITCODIAC	391	2.99	0.76	1029.2	123.76	155.2	651.69	45.9436	65.1703
01BU003	TURTLE	129	0.4	0.31	1311.2	125	57.25	892.30	45.9581	64.8789
01BU004	PALMER'S	34.2	0.05	0.148	1212.5	98	28.15	861.25	45.8872	64.5164
01BV006	POINT WOLFE	130	1.36	1.05	1389.7	139.6	72.25	1278.42	45.5589	65.0172
01DL001	KELLY	63.2	2.706	4.29	1250	50	39.8	983.01	45.5861	64.4514

FIG. 2: Mean Annual Precipitation (1951-1980)

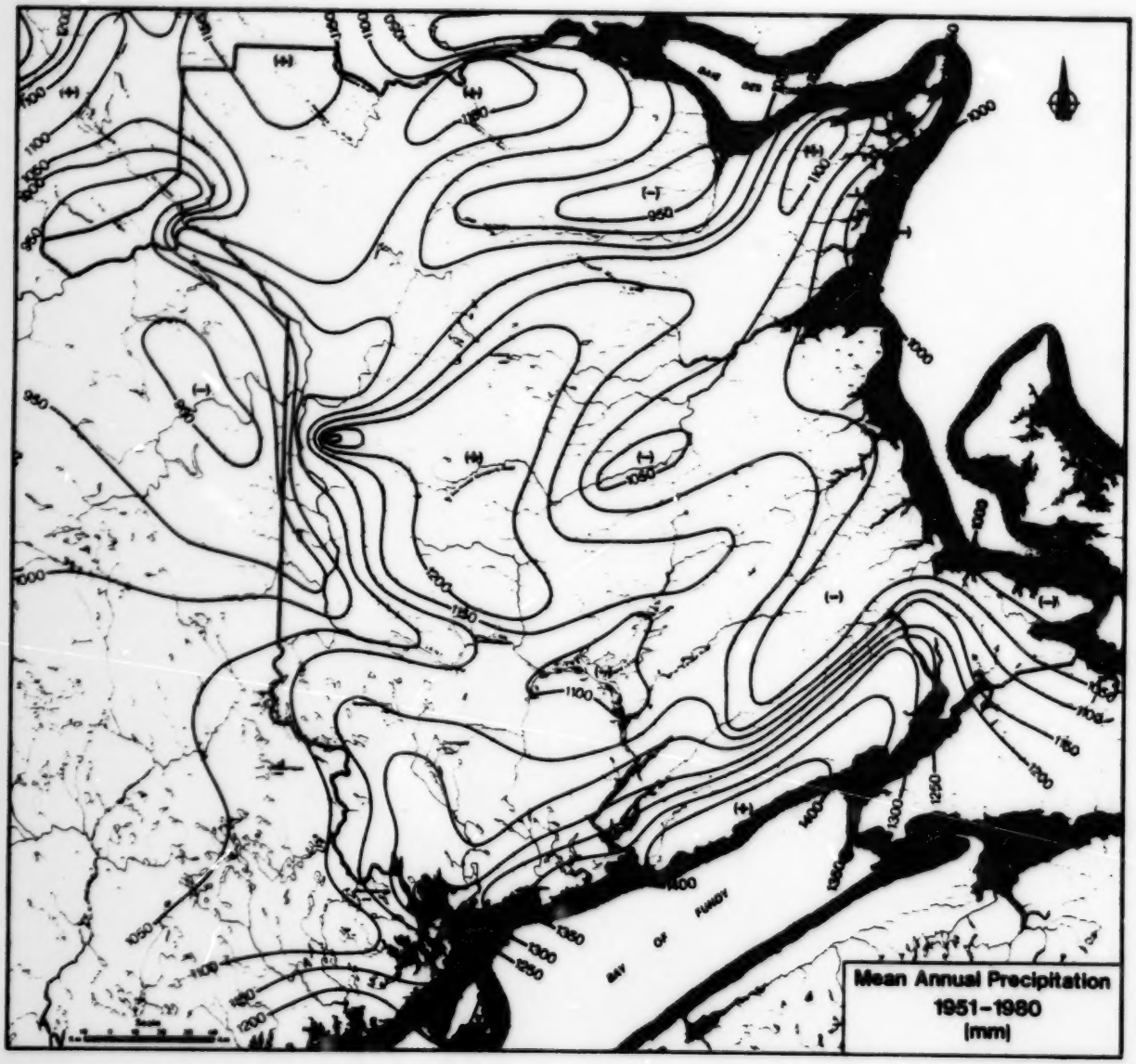

Fig. 2

TABLE 6

REGIONAL REGRESSION EQUATIONS FOR THE

NORTHERN REGION

$$LF_{T,D} = (c\sqrt{DA} + d\sqrt{MAP} + k)^2$$

RETURN PERIOD	DURATION	c	d	k	r^2	S.E.(m^3/s)
2 year	1 day	0.049	0.245	-7.966	0.9987	0.379
	7 day	0.051	0.250	-8.121	0.9992	0.318
	14 day	0.052	0.248	-8.059	0.9992	0.332
10 year	1 day	0.039	0.222	-7.239	0.9949	0.454
	7 day	0.040	0.240	-7.820	0.9943	0.503
	14 day	0.041	0.251	-8.162	0.9956	0.462
20 year	1 day	0.037	0.206	-6.701	0.9937	0.452
	7 day	0.038	0.232	-7.532	0.9902	0.586
	14 day	0.038	0.249	-8.076	0.9917	0.562

NOTE:

Range of independent variables used in regression equations:

$173.0\ km^2 < DA < 14{,}700\ km^2$
$988.4\ mm < MAP < 1183.9\ mm$

Number of stations in region: 11

The general form of the Southern Region equation for basins with drainage areas greater than or equal to 400 km^2 is as follows:

$$LF_{T,D} = (e\sqrt{MAP} + f\sqrt{P} + g\sqrt{LAT} + k)^2$$

where LF = the low flow (m^3/s); for return period T and duration D;
MAP = the mean annual precipitation (mm) of the basin;
P = the perimeter (km) of the drainage basin upstream of the point of interest;
LAT = the latitude (^{o}), with minutes and seconds expressed as a decimal, of the outlet of the basin at the point of interest;
e,f,g = regression coefficients from Table 7; and
k = regression constant from Table 7.

The Southern Region equation for basins with drainage areas less than 400 km^2 is in the following general form:

$$LF_{T,D} = \frac{l(MAP) + m(P) + n(LAT) + k}{100}$$

where LF = the low flow (m^3/s); for return period T and duration D;
MAP = the mean annual precipitation (mm) of the basin;
P = the perimeter (km) of the drainage basin upstream of the point of interest;
LAT = the latitude (^{0}), with minutes and seconds expressed as a decimal, of the outlet of the basin at the point of interest;
l,m,n = regression coefficients from Table 8; and
k = regression constant from Table 8.

TABLE 7

REGIONAL REGRESSION EQUATIONS FOR THE

SOUTHERN REGION BASINS WITH DRAINAGE BASIN AREAS ≥ 400 km²

$$LF_{T,D} = (e\sqrt{MAP} + f\sqrt{P} + g\sqrt{LAT} + k)2$$

RETURN PERIOD (T)	DURATION (D)	e	f	g	k	r^2	S.E. (m^3/s)
2 Year	1 Day	-	0.263	-	-2.255	0.9726	0.964
	7 Day	0.146	0.254	6.111	-48.431	0.9923	0.604
	14 Day	0.140	0.262	6.256	-49.248	0.993	0.616
10 Year	1 Day	0.162	0.211	6.763	-53.283	0.9920	0.394
	7 Day	0.156	0.217	7.033	-54.899	0.9921	0.418
	14 Day	0.155	0.223	7.239	-56.337	0.9918	0.455
20 Year	1 Day	0.160	0.201	7.079	-55.291	0.9908	0.379
	7 Day	0.160	0.209	7.375	-57.333	0.9919	0.389
	14 Day	0.165	0.215	7.496	-58.372	0.9910	0.436

NOTE:

Range of independent variables used in regression equations:

925.0 mm < MAP < 1213.4 mm
103.6 km < P < 611.5 km
45.6736° < LAT < 46.8886°

Number of stations in region (≥ 400 km²): 11

TABLE 8

REGIONAL REGRESSION EQUATIONS FOR THE SOUTHERN REGION BASINS WITH DRAINAGE BASIN AREAS < 400 km^2

$$LF_{T,D} = \frac{l(MAP) + m(p) + n(LAT) + k}{100}$$

RETURN PERIOD	DURATION	l	m	n	k	r^2	S.E. (m^3/s)
2 Year	1 Day	0.108	0.517	27.782	-1415.187	0.7513	0.092
	7 Day	0.123	0.591	29.259	-1501.586	0.7491	0.105
	14 Day	0.127	0.663	29.558	-1521.554	0.7513	0.118
10 Yr.	1 Day	0.083	0.280	25.285	-1268.547	0.7223	0.058
	7 Day	0.098	0.338	29.052	-1460.184	0.7506	0.064
	14 Day	0.107	0.381	31.460	-1583.080	0.7522	0.071
20 Yr.	1 Day	0.083	0.251	24.736	-1243.201	0.7550	0.049
	7 Day	0.097	0.306	28.767	-1446.743	0.7849	0.054
	14 Day	0.106	0.340	31.012	-1561.309	0.7978	0.057

NOTE:

Range of independent variables used in regression equations:

975.0 mm < MAP < 1389.7 mm
28.1 km < P < 155.2 km
45.2033° < LAT < 46.8283°

Number of stations in region (<400 km^2): 16

The coefficients of determination, r-squared and the standard errors of the regression equations, are provided in Tables 6, 7 and 8 for each of the regression equations. Tables 6, 7 and 8 also indicate the range of the physiographic/climatic variables that were used to derive the equations. The equations are limited by the range used to develop them and should not be applied outside the stated ranges without carefully considering effects on the accuracy of the low flow estimate.

While conducting this study, it was realized that the reliability of the derived regression equations for low flow estimation will be limited due to gaps in geographic coverage of hydrometric stations with varying sizes of drainage basins. For example, there are no hydrometric records for small unregulated basins in northwestern New Brunswick available for use in the regression analyses. The smaller gauged drainage basins (< 400 km^2) are all located in the eastern portion of the Northern Region. This makes application of the equations to small basins in the northwestern part of the province more doubtful. Therefore, the user should exercise professional judgement in this instance.

3.3 Envelope Curves

Envelope curves provide a quick and simple technique to estimate low flows, but they are generally known to lead to lower estimates than regional equations. These curves are developed by plotting the low flows for a given return period against their

drainage areas and drawing a lower bound on the data. The 1, 7, 14 day low flows are so close that a single curve was prepared for the return periods (2, 10, 20 and 50 years).

For the most part, these curves indicate, based on the available data collected, a lower limit for low flows. For example, low flow estimates for watersheds with a significant degree of storage in the form of lakes and swamps could tend to be significantly under-estimated. However, in the case of steep streams having little groundwater inflow, it is still possible that curves may over-estimate low flows.

During design, remember that low flow envelope curves almost always provide an underestimate of low flows. However, for several design situations, a conservative estimate as provided by envelope curves might prove to be useful to at least provide a reasonable starting point.

Figure 3 shows the curves for the 2, 10, 20 and 50 year low flows.

LOW FLOW ENVELOPE CURVES

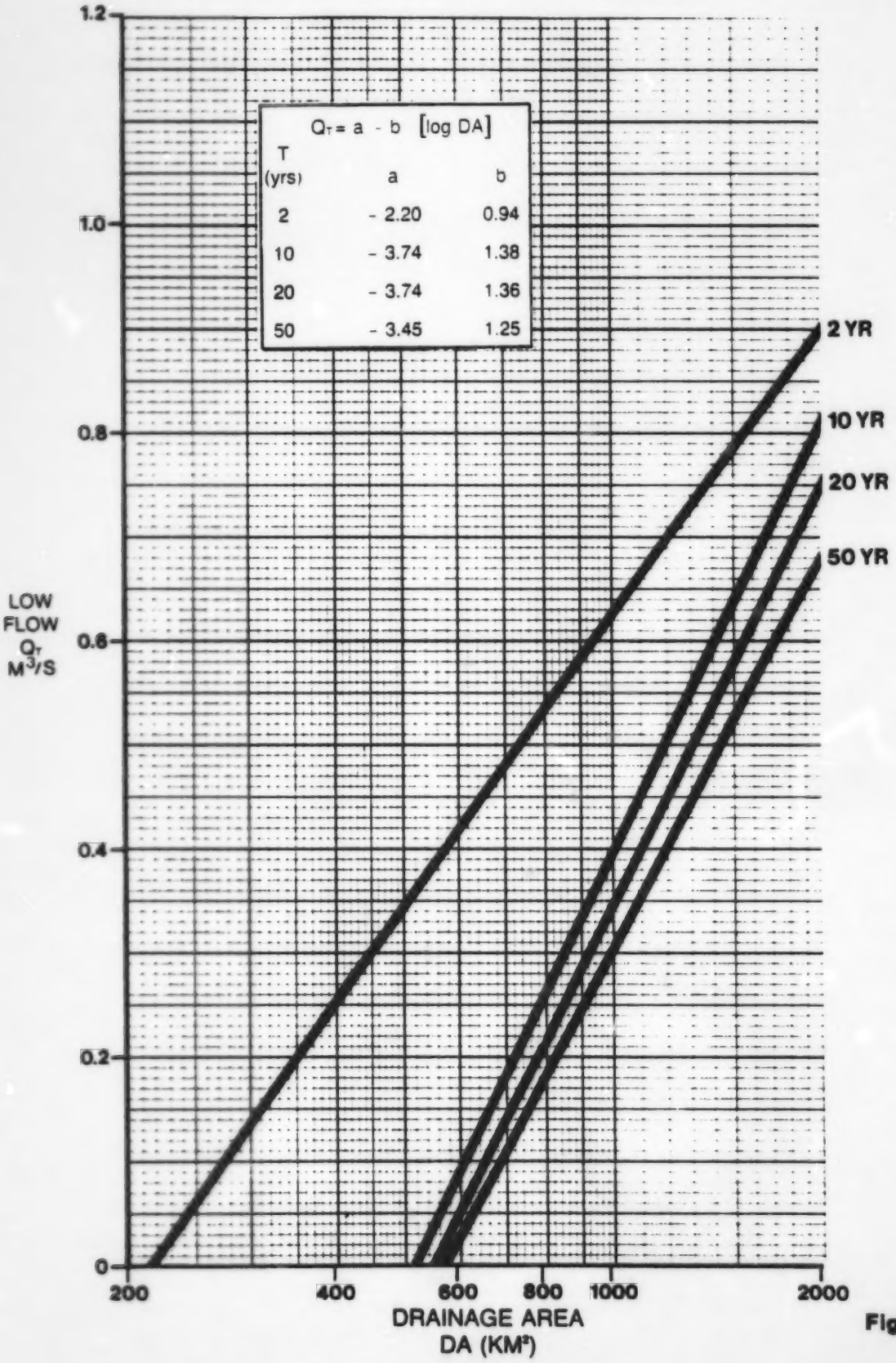

Fig. 3

Equations of the following form describe the envelope curves.

$Q_T = a + b[\log DA]$ with $Q_T \geq 0$ Always

where Q_T = one day duration low flow from the envelop areas for a recurrence interval T in years;

a = equation constant;

b = equation coefficient; and

DA = drainage area.

According to the envelope curves, zero flows can occur at the 2, 10, 20 and 50 year return periods for basins less than, respectively, 217, 514, 558 and 574 km^2 respectively. Because of the scarcity of data for large basins, the curves were not extended for drainage areas larger than 2000 km^2.

4.0 APPLICATIONS PROGRAM

A user-friendly interactive computer program "HIGHLOW" has been prepared to estimate flood or low flows by proration of the results of single station frequency analyses, or by the use of regional regression equations.

The computer program "HIGHLOW" has been prepared to allow regional regression equations presented in this report to be readily used. Selection of the proper regression equation and coefficients is done by the program once the region, desired return period, and desired duration have been specified. The user is then prompted for the required physiographic and climatic parameters in a regional analyses, or drainage area in the case of single station proration.

The program is an aid to low flow estimation for those individuals who may have difficulty in interpreting and using sections of this report. The program also eliminates calculation errors and mistakes in looking up regression coefficients and constants.

The program can also be used for regional flood flow estimation based upon the regional equations presented in the flood frequency analyses report (Environment Canada and New Brunswick

Department of Municipal Affairs and Environment, 1987). Refer to the report for an outline of the methodology for calculating flood flows.

The program was written for IBM compatible computers. Please contact the Water Resource Planning Branch, N.B. Department of the Environment, P.O. Box 6000, Fredericton, New Brunswick, E3B 5H1, (telephone number: (506) 453-2353) to request copies of this program.

5.0 LOW FLOW ESTIMATION PROCEDURE DESCRIPTION

5.1 General

A description of how to estimate design low flows using the results of this study is given in this section. The procedural steps given in this description are only intended to provide guidance to the user of the report.

Before proceeding with low flow estimation, the desired return period and duration must be chosen. In New Brunswick, the following low flows have commonly been used:

- 10 year return period, 7 day duration low flow for environmental protection and sanitary engineering design; and
- 20 year return period, 7 day duration low flow for municipal or industrial water supply projects.

The user may decide upon a different duration or return period depending upon the particular application being considered. The degree of acceptable risk must be evaluated when making this decision.

The procedure for low flow estimation at the site of a streamflow gauging (hydrometric) station and for ungauged sites differ and are outlined separately below.

5.2 Low Flow Estimation at Gauged Sites

(1) Using the application computer program "HIGHLOW", or Table 1, identify the station and corresponding number of the hydrometric station for which a flood flow estimate is required.

(2) Using the results of the single station frequency analyses as provided by the computer program "HIGHLOW", or given in Tables 2, 3 and 4, obtain low flow(s) for the required recurrence intervals and duration.

For low flows of:

- one day duration use Table 2.
- seven day duration use Table 3.
- fourteen day duration use Table 4.

(3) Single station frequency analysis can be performed using more up-to-date data, if available. (The Water Resource Planning Branch has a computer program "MONTHLF" which calculates annual and monthly low flows of any duration from an Environment Canada, Water Resources Branch daily discharge data set. This program is available upon request.)

(4) If a natural flow station had less than 10 years of record as of the end of 1987, it will not be in Table 1 and the user is referred to (3) above or to the following section for ungauged sites.

5.3 Low Flow Estimation at Ungauged Sites

(1) Locate the site on a topographic map and delineate the drainage divide upstream of the ungauged site.

The following guidelines may be followed in the selection of National Topographic Systems (NTS) map scales.

Area in km^2	Scale of Map
> 2000	1:250,000
200-2000	1:50,000
< 200	Use air photos or larger scale maps, using the 1:50,000 scale map as a reference guide.

(2) Use Figure 1 to determine in which region the basin is located.

There are two regions: a Northern Region and a Southern Region.

The Miramichi River Basin lies in both regions. The Northwest Miramichi River and its tributaries are considered to be within the Northern Region. The Southwest Miramichi River and its tributaries are considered to be within the Southern Region. However, if a drainage basin under consideration is near or borders the boundary between the regions, it may be

worthwhile to compare the results obtained using both appropriate relationships for both the Northern Region and Southern Region.

If within the Southern Region, it will also be necessary to ascertain if the drainage area of the basin under consideration is greater than or equal to 400 km^2 or less than 400 km^2 (see Step 8). It may be worthwhile to compare results obtained using the relationships for both larger and smaller basins when the drainage area is around 400 km^2.

(3) Decide upon the desired return period and duration. This depends upon the risk acceptable to the user. In this report, information is presented by which low flows can be determined for three different return periods (2, 10, and 20 years) and for three different durations (1, 7 and 14 days).

(4) Determine whether or not there is a hydrometric station located nearby in the same basin. If a hydrometric station does not exist nearby, proceed to Step 5, which outlines the regional analysis methodology.

If a hydrometric station in the same basin or similar basin nearby does exist, then proceed using the proration methodology outlined below or use the computer program "HIGHLOW" (select the single station proration option).

The estimate of low flow is obtained by multiplying the results of a single station low flow frequency analysis at the gauge site by the ratio of drainage basin areas as follows.

$$(LF_{\text{at ungauged site}})_{T,D} = (LF_{\text{at gauged site}})_{T,D} \frac{(DA_{\text{ungauged site}})}{(DA_{\text{gauged site}})}$$

where LF = low flow; and
DA = drainage area.

An adjustment, based on engineering judgement, may also be required to reflect the effect due to differing physiographic and hydrometeorologic parameters.

If the difference in surface areas is greater than 10%, considerable care must be exercised in prorating basins. Generally, proration should not be used when the difference in area is greater than 50%. The greater the difference in area, the greater the uncertainty in low flow estimation will be.

(5) Estimate required parameters.

Mean annual precipitation (MAP) in mm must be estimated as it is a parameter in all regression equations. Determine the mean annual precipitation <u>for the drainage basin</u> using Figure 2.

A weighted areal average is the best approach with a value at the basin centroid being the next best alternative. Interpolation with nearby meteorological stations is also acceptable, but not as accurate, especially for large watersheds. The sensitivity of low flows to MAP can be evaluated by using the range of MAP values for the basin in the regression equations.

For a basin within the Northern Region, the only other parameter required is drainage area (DA) upstream of the site. This is determined by measuring the area within the drainage divide delineated in Step 1.

For a basin within the Southern Region, the perimeter (P) of the drainage basin and latitude (LAT) of the basin outlet at the point of interest must be determined. Both parameters can be obtained using NTS maps.

(6) Determine whether or not the parameters fall within the specified ranges for which the equations are considered to be applicable as given at the bottom of Tables 6, 7 and 8. The closer the value of any parameter to the limits of the range for that parameter, the greater is the uncertainty associated with the flow estimate(s).

If any parameter value falls outside the specified range, the estimated low flow value will be less reliable. The use of an alternate equation will eliminate the problem parameter from computations, but the problem parameter may still have a significant influence on flows. In this case, the low flow estimate could be compared to that obtained by prorating to a nearby single station to get an appreciation of the possible reliability of the estimate.

If using the interactive computer program "HIGHLOW", a warning message is provided if a parameter value is input which falls outside the specified range.

Mean annual precipitation (MAP) is an important parameter and appears in all the regression equations. If its value falls outside the range, the equation(s) cannot be expected to provide satisfactory flow estimates.

(7) Select the appropriate constant and coefficients from Table 6, 7, or 8 for the desired return period and duration daily mean low flow(s), or use the computer program "HIGHLOW".

Please note that separate relationships have been presented for the Northern Region; for basins in the Southern Region greater than or equal to 400 km^2 in area; and for basins in

the Southern Region less than 400 km^2 in area. The constants and coefficients are not interchangeable for different relationships.

(8) Compute the low flow estimate(s) using the equation(s) selected along with the relevant parameters, constant, and coefficients.

When using equations for Southern Regions less than 400 km^2, remember that the value obtained from the numeration of the right hand side of the equation must be divided by 100 to obtain an estimate of low flow.

Engineering judgement must be exercised. Consideration must be given to all parameters that may affect low flows.

6.0 ILLUSTRATIVE EXAMPLES

The following examples should be of assistance in understanding the above procedures.

Example One: **DETERMINE LOW FLOW AT A GAUGED SITE**

Determine: The 10 year return period, 7 day duration low flow, for the Saint John River at Fort Kent.

Drainage Area: From Table 1 entitled "Summary of Hydrologic Information for Selected Hydrometric Stations", the drainage area upstream of the Saint John River at Fort Kent, Station No. 01AD002, is 14,700 km^2.

Solution: (1) Single Station Frequency Analysis

Using Table 1, station Saint John River at Fort Kent, is identified as Station No. 01AD002. From Table 2, entitled "Results of Single Station Flood Frequency Analyses" ten year return period, 7 day duration low flow of 20.49 m^3/s can be obtained.

(2) Regional Low Flow Frequency Analysis

The Saint John River at Fort Kent is within the Northern Region (refer Figure 1).

Mean annual precipitation (MAP) in mm can be determined from Table 5 as 996.9 mm.

From Table 6 entitled "Regional Regression Equations for the Northern Region", the regression constant and coefficients for the 10 year return period, 7 day duration low flow (Northern Region) are:

k = -7.820;
c = 0.040; and
d = 0.240.

Substituting the values into the equation:

$LF_{10,7} = (c\sqrt{DA} + d\sqrt{MAP} + k)^2$

yields:

$LF_{10,7} = \underline{21.3\ m^3/s}$.

Results: Estimates of the 10 year return period, 7 day duration low flow for the Saint John River at Fort

Kent (Station No. 01AD002) have been obtained. From the single station frequency analysis the value is 20.5 m^3/s, while using the Northern Region equation the estimation is 21.3 m^3/s.

Commentary: In practical applications, a comparison of a prorated low flow estimate using the single station frequency analysis from a nearby gauge will be made to the low flow estimate based on the regional regression equations. In this case, the single station frequency analysis low flow estimate of 20.5 m^3/s was based on a proration factor of 1.0 since the ungauged site of interest was actually the site of the gauge itself.

The results obtained from the single station frequency analysis and using the Northern Region equation differ only by 3.9%. Where it is known that the single station estimate using the recorded data is accurate, it can be inferred that this error is attributable to the regional regression approach.

The station Saint John River at Fort Kent is the largest used in this study.

Example Two: **DETERMINE LOW FLOW AT AN UNGAUGED SITE BUT WITH A NEARBY GAUGE IN THE SAME BASIN**

The following example outlines the procedure that may be followed if a hydrometric station is located nearby on the same stream. (Refer to Step 4 for ungauged sites, Section 5.3).

Determine: The 10 year return 7 day period duration low flow, $LF_{10,7}$, for the Upsalquitch River at Robinsonville.

Solution: From Figure 1, it can be determined that the Upsalquitch River lies within the Northern Region.

Streamflow gauging Station No. 01BE001, Upsalquitch River at Upsalquitch, is nearby. From Table 1, the drainage area at the gauging station is 2270 km^2.

The drainage divide for the portion of the Upsalquitch River basin upstream of Robinsonville but downstream of the gauging station was outlined on 1:50000 scale topographical maps. The drainage

drainage area of this portion of the basin was then determined by planimetry to be approximately 62.3 km^2.

The drainage basin of the Upsalquitch River at Robinsonville is thus 2270 km^2 + 62.3 km^2 = 2332 km^2.

The drainage areas of the Upsalquitch River basins at the gauging station and at Robinsonville differ by less than 10% therefore it is expected that the results of the single station frequency analysis for the Upsalquitch River at Upsalquitch would provide the best estimate of low flow.

From Table 3 for Station No. 01BE001, the 10 year return period, 7 day duration low flow is 3.89 m^3/s.

Prorating using drainage basin area can be performed as follows:

$$LF_{10,7} \text{ at Robinsonville} = (3.89\ m^3/s)\ \frac{2332\ km^2}{2270\ km^2}$$

$$LF_{10,7} = 4.0\ m^3/s.$$

The Northern region regression equation can also be used (similar to previous example) to obtain a low flow estimate as follows, however, this would not be expected to be as good an estimate in this case.

The equation is:

$$LF_{10,7} = (c\sqrt{DA} + d\sqrt{MAP} + k)^2$$

From Figure 4, titled "Mean Annual Precipitation 1951-1980", MAP for the Upsalquitch River Basin upstream of Robinsonville can be determined to be approximately 1050 mm.

Both drainage area and mean annual precipitation are within the range of independent variables used in the regression equations for the Northern Region as provided at the bottom of Table 6.

From Table 6, titled "Regional Regression Equations Northern Region", for the 10 year return period, 7 day duration low flow, c = 0.040, d = 0.240 and k = -7.820.

Substituting yields:

$$LF_{10,7} = 3.57 \text{ cms}$$

Results: The 10 year return period, 7 day duration low flow estimate for the Upsalquitch River at Robinsonville is 4.0 $m^3/_s$ by prorating the ratio of drainage areas to the nearby station, while by using the Northern regression equation the value is 3.6 m^3/s.

Commentary:

As the hydroclimatic and physiographic conditions of the lower basin do not differ greatly from that of the entire basin, prorating the results of the single station frequency analysis for the gauging station at Upsalquitch should provide the best estimate. However, it may be wise to use a lower flow estimate, depending on the degree of risk involved.

Example Three: **DETERMINE LOW FLOW AT AN UNGAUGED SITE**

Usually, streamflow gauging stations are not located adjacent to or in the vicinity of a proposed project. Therefore, the regional regression equations, or some other means, must be used to estimate low flows at ungauged locations. In the previous example, there was only one regional regression equation that was applicable.

In this example, a site (the Southwest Miramichi River near Juniper at the Forks) was selected where the choice of regression equation is less obvious.

Determine: The 20 year recurrence interval, 7 day duration low flow, $LF_{20,7}$, for the Southwest Miramichi River near Juniper at the Forks.

Solution: From Figure 1 titled "Homogeneous Low Flow Regions and Hydrometric Stations Used in the Analysis", it can be seen that the Southwest Miramichi River near Juniper at the Forks lies within the Southern Region. However, the upstream area of the drainage basin borders the Northern Region. Therefore, the regional regression equations for both the Northern and Southern regions will be used in this example and the results compared.

Mean annual precipitation can be estimated from Figure 2 titled "Mean Annual Precipitation (1951 - 1980)" to be 1105 mm.

The drainage divide was outlined on 1:50 000 scale topographical maps and the area determined by planimetry to be approximately 673 km^2.

The perimeter was determined as 195.9 km. Latitude of the basin at the outlet was determined to be 46.314°N.

The variables are within the acceptable ranges given for the equations in Tables 6 and 7.

The equation for the Southern Region ($DA \geq 400\ km^2$) is of the form:

$$LF_{T,D} = (e\sqrt{MAP} + f\sqrt{P} + g\sqrt{LAT} + k)^2$$

From Table 7, for the 20 year return period, 7 day duration low flow, e = 0.160, f = 0.209, g = 7.375 and k = -57.333.

Substituting into the above equation and solving yields:

$$LF_{20,7} = 1.22\ m^3/s$$

The equation for the Northern Region is of the form:

$$LF_{20,7} = (c\sqrt{DA} + d\sqrt{MAP} + k)^2$$

From Table 6, for the 20 year return period, 7 day duration low flow, c = 0.038, d = 0.232 and k = -7.532.

Substituting into the above equation and solving yields:

$$LF_{20,7} = 1.36 \ m^3/s.$$

Results: Estimates of the 20 year return period, 7 day low flow for the Southwest Miramichi River at the Forks:

Using the Northern Equation the estimate is 1.36 m^3/s while using the Southern Equation (DA < 400 km^2) the estimate is 1.22 m^3/s.

Commentary: Similar results were obtained using the Northern and Southern Region equations, therefore it gives greater confidence in the accurracy of the estimates. This may not always be the case, especially for smaller basins.

6.1 REFERENCES

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